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Catalogue of topographical mineralogies and regional bibliographies.

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SOME time previous to 1894 the late Sir Henry A. Miers, then an assistant in the Mineral Department of the British Museum, collected together all the books in the departmental library which gave a systematic account of the minerals of particular regions. Since then the set has been considerably added to, and it now forms a very valuable, probably unique, series. Its primary use was for the more precise labelling of the localities of specimens in the collection; and as it grew it became more and more useful for answering inquiries on the minerals of particular districts. In 1900 I started a note-book for collecting further references from the literature. This was added to by the late Mr. George Savigar, clerk in charge of the departmental library; and later Miss J. M. Sweet compiled a card-index of all the entries. The department also has card-indexes of the localities of mineral and rock specimens in the collection.

In the following list a selection has been made for general use of the more important of these works. Some early references and first editions are included as being of historical interest. With those of later date a reference is given to reviews in the Mineralogical Magazine (M.M.) and Mineralogical Abstracts (M.A.), from which some further information as to scope may be obtained. Much scattered information on the occurrences of minerals is contained in the publications of the Geological Surveys and Mines Departments of various countries. For example, 'The geology of Falmouth and Truro and of the mining districts of

Camborne and Redruth' (Mem. Geol. Surv. England and Wales, 1906, Explanation of Sheet 352) contains lists of minerals and mines and a detailed bibliography. Only a few such works have been listed when necessary to fill gaps: to include all would add unduly to the length of the list.

The geographical arrangement is based on that scheduled for the International Catalogue of Scientific Literature (1901–14), which has since been followed in the topographical indexes of Mineralogical Abstracts.

The bibliographies listed are mostly those relating to the geology of countries, but these include also mineralogy, petrology, and economic minerals. Only those covering longer periods of time (e.g. Finland 1555–1933) are included, to the exclusion of annual bibliographies.

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Riemann (C.). Topographische Uebersicht der Mineralien. *In* Taschenbuch für Mineralogen, pp. 254–301. Berlin, 1877.

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Brendler (W.). Mineralien-Sammlungen. 2 vols. Leipzig, 1908–12. (Geographical index in vol. 2, pp. 547–696.)

Kaiser (E.). Ortsregister zur Band 1 bis 55 der Zeitschrift für Kristallographie und Mineralogie. 522 pp. Leipzig, 1931. [M.A. 5–85.]

International catalogue of scientific literature, Mineralogy, vols. 1–14 (for 1901–14). London, 1903–17. (Geographical distribution.)

Mineralogical Magazine, General Index to vols. 11–20 (1895–1925). London, 1926. (Topographical index, pp. 1–22.)

Mineralogical Abstracts, vols. 1–9, 1920–46. (Topographical index in each volume.)

EUROPE

Slavík (F.) & Spencer (L. J.). Place-names of mineral-localities in central Europe. Min. Mag., 1928, vol. 21, pp. 441–479. (Alphabetical index of all the place-names in twelve languages in M.A. 3.)

Iceland (Ísland)

Schumacher (C. F.), 1801. *v.* Denmark.

Sartorius von Waltershausen (W.). Über die vulkanischen Gesteine in Sicilien und Island. 548 pp. Göttingen, 1853.

— Geologischer Atlas von Island. 25 pls. Erlauterungen, 65 pp. Göttingen, 1853.

Gratacap (L. P.). The minerals of Iceland. Bull. New York Min. Club, 1907, vol. 1, no. 1, 9 pp.; reprinted in The Mineral Collector, New York, 1907, vol. 14, pp. 46–48, 61–63, 77–80.

Faeroes (Færøerne)

Schumacher (C. F.), 1801. *v.* Denmark.

Allan (T.). An account of the mineralogy of the Faroe Islands. Trans. Roy. Soc. Edinburgh, 1815, vol. 7, pp. 229–267, map (1 in. = 6 m.).

Currie (J.). The mineralogy of the Færöes, arranged topographically. Trans. Edinburgh Geol. Soc., 1907, vol. 9, pp. 1–68, map (1:800,000).

Görgey (R.). Ein Beitrag zur topographischen Mineralogie der Färöer.

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Rasmussen (J.). Oversigt over den geologiska litteratur vedrørende Færøerne. Meddel. Dansk Geol. For., 1947, vol. 11 (for 1946), pp. 66–96.

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Schumacher (C. F.), 1801. *v.* Denmark.

Brøgger (W. C.). Die Mineralien der Syenitpegmatitgänge der südnorwegischen Augit- und Nephelinsyenite. Zeits. Kryst. Min., 1890, vol. 16, 916 pp., 27 pls., 2 maps (1:50,000).

— Die Eruptivgesteine des Kristianiagebietes. 7 pts., 1487 pp., maps. Vid.-selsk. Skrifter, Kristiania, 1894–1933.

— Die Mineralien der südnorwegischen Granitpegmatitgänge. I. Niobate, Tantalate, Titanate und Titanoniobate. Ibid., 1906, no. 6, 162 pp., map (1:2,000,000).

— Vogt (T.), & Schetelig (J.). Die Mineralien der südnorwegischen Granitpegmatitgänge. II. Silikate der seltenen Erden (Y-Reihe und Ce-Reihe). Ibid., 1922, no. 1, 155 pp. [M.A. **2**–25.]

Bjørlykke (H.). Feltspat V. De sjeldne mineraler på de norske granittiske pegmatittganger. Norges Geol. Undersök., 1939, no. 154, 78 pp. [M.A. **9**–200.]

Neumann (H.). Silver deposits of Kongsberg. Norges Geol. Undersök., 1944, no. 162, 133 pp. [M.A. **9**–200.]

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— Handbok för mineraloger under resor i Sverige. 194 pp. Stockholm, 1843.

Erdmann (A.). Försök till en geognostisk-mineralogisk beskrifning öfver Tunabergs socken i Södermanland. Svenska Vet.-Akad. Handl., 1843, pt. 2, 94 pp., maps. Transl. by F. Creplin in Neues Jahrb. Min., supplement, 1851.

Igelström (L. J.). Mineralogisk vägvisare in Wermland. 46 pp. Karlstad, 1871.

Flink (G.). Bidrag till Sveriges mineralogi. 4 pts., 668 pp. Arkiv Kemi, Min. Geol., 1908–17, vol. 3 (nos. 11 & 35), vol. 5 (no. 10), vol. 6 (no. 21). [Ends abruptly in the middle of the silicates and never completed.]

— Lista på mineral från Långban. Geol. För. Förh. Stockholm, 1921, vol. 43, pp. 195–201; 1922, vol. 44, pp. 535–539. [M.A. **2**–261.]

— Über die Långbansgruben als Mineralvorkommen. Zeits. Krist., 1923, vol. 58, pp. 356–385, maps. [M.A. **2**–261.]

— Långban and its minerals. Amer. Min., 1926, vol. 11, pp. 195–199. [M.A. **3**–442.]

— Bidrag till Malmbergsgruvornas och Kiirunavaaras mineralogi. Vetensk. Prakt. Undersök. Lappland, 1924, Lapplandsgruvornas mineralogi, no. 7, 196 pp.

Sjögren (H.). Contributions to Swedish mineralogy. Bull. Geol. Inst. Univ. Upsala, 1893, vol. 1, pp. 1–64; 1895, vol. 2, pp. 37–108.

Quensel (P.) *et al.* Minerals of the Varuträsk pegmatite. Geol. För. Förh. Stockholm, 1937–46, vols. 59–68. (A series of 37 papers.) [M.A. **6**–9.]

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— Geologische Bibliographie Finnlands 1555–1933. Bull. Comm. Géol. Finlande, 1934, no. 108, 224 pp. [M.A. **7**–326.]

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A note on the thermal decomposition of chrysotile.

(With Plate XIX.)

By M. H. Hey, M.A., D.Sc., and F. A. Bannister, M.A., Sc.D., F.Inst.P.
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[Read January 22, 1948.]

DURING the course of a detailed X-ray study of chrysotile, antigorite, and gümbelite by E. Aruja[1] we were asked to confirm some interesting results he had obtained on heating chrysotile to various temperatures. This we were able to do and also to provide additional data which were recently referred to in a paper by A. Hargreaves and W. H. Taylor.[2] Although we have not succeeded in providing a completely satisfactory explanation of the optical changes observed on heating chrysotile our observations for a limited range of temperatures in the neighbourhood of 1000° C. are here recorded.

Aruja has found that the X-ray pattern for chrysotile begins to disappear after heating to 600–620° C. and that simultaneously a partially oriented pattern of forsterite appears comprising sharp reflections linked by powder lines. X-ray photographs of chrysotile heated to higher temperatures show an enhanced oriented spot-pattern of forsterite and a weakening of the forsterite powder lines. We obtained the same results on heating a specimen of chrysotile fibre (pl. XIX, figs. 1, 2) and were able to confirm Aruja's statement that after heating at 1000° C. the predominant pattern is due to forsterite and that enstatite is not formed in sufficient quantity to be recorded by X-rays. Chrysotile does not, therefore, break down on heating according to the reaction

$$H_4Mg_3Si_2O_9 \rightarrow Mg_2SiO_4 \text{ (forsterite)} + MgSiO_3 \text{ (enstatite)} + 2H_2O$$

as suggested by Mlle Caillère.[3]

Chrysotile when heated loses its flexibility and becomes brittle, changing in colour from green to gold or straw-yellow. We have obtained optical data on three heat-treated samples from the same

[1] E. Aruja. Dissertation for Ph.D. degree, University of Cambridge, 1943; Min. Mag., 1945, vol. 27, pp. 11 and 65.

[2] A. Hargreaves and W. H. Taylor, Min. Mag., 1945, vol. 27, p. 204.

[3] S. Caillère, Bull. Soc. Franç. Min., 1936, vol. 59, p. 163. [M.A. 6–475.]

specimen[1] which agree with those measured by Professor C. E. Tilley and recorded by Aruja for chrysotile from Thetford, Quebec.

No.	Temperature. ° C.	Duration of heat-treatment.	Refractive indices.	Sign of elongation.
1	900	5 hours	1·56–1·57	positive
2	1000	5 hours	1·59	positive
3	1000	12 hours	1·61–1·62	negative

All three samples yield an oriented photograph of forsterite (pl. XIX, fig. 2), the powder lines giving place to distinct spots and the perfection but not the nature of the orientation improving from nos. 1 to 3. There is no further increase of refractive index or change in the sign of elongation when chrysotile is heated for longer periods at 1000° C.

After an examination of chrysotile heated by Aruja, Professor Tilley suggested that the low refractive index of the product compared with that of forsterite (β 1·65) might be due to the liberation of free silica (n 1·46) and that decomposition proceeds according to the reaction:

$$2H_4Mg_3Si_2O_9 \rightarrow 3Mg_2SiO_4 + SiO_2 \text{ (silica gel)} + 4H_2O.$$

Our X-ray photographs of heated chrysotile show low-angle background scattering, some of which may be due to the presence of amorphous material. It has not been possible, however, to detect the broad haloes characteristic of silica gel. We therefore attempted a physical separation of free silica from the heated chrysotile. A small quantity of no. 3 was ground in a mortar and centrifuged for an hour in bromoform. No separation of a component with specific gravity $<2{\cdot}85$ could be detected, however finely the sample was ground before centrifuging.

As this preliminary attempt at a physical separation of silica failed we turned to a chemical method. Samples of olivine, unheated chrysotile, and two of the heated samples nos. 1 and 3 were finely ground and then boiled gently for 15 mins. with 50 c.c. of 10 % caustic soda. The mixture was filtered and silica determined in the filtrate. The following data were obtained by Miss Hilda Bennett:

Silica extractions from:

Pale green olivine	3·2 %
Unheated chrysotile	3
Chrysotile heated to 900° C. for 5 hours (no. 1) ...	18·8
Chrysotile heated to 1000° C. for 12 hours (no. 3) ...	6·3

These results encouraged us to attempt a physical separation of the components of chrysotile heated to 900° C. for 5 hours (no. 1). This

[1] B.M. 83118. Chrysotile; Johnson mine, Thetford, Megantic Co., Quebec. Compact, oil-green, yielding fibres 8½ cm. long, α 1·535, γ 1·550, positive elongation.

time the specimen was ground for $\frac{1}{2}$ hour before centrifuging. A separation into two fractions, *A* with specific gravity just $<2{\cdot}85$ and the darker fraction *B* specific gravity $>2{\cdot}85$ was achieved. Both fractions consist of pale yellow fragments of low birefringence (grey) with refractive index 1·56–1·57. The darker fraction *B* of higher specific gravity contains some opaque fragments confirmed as haematite by an X-ray photograph. Powder photographs of fraction *A* taken with copper radiation and repeated with cobalt radiation reveal only forsterite lines (pl. XIX, fig. 3). Spots due to haematite as well as forsterite lines were observed on the photographs of fraction *B*, but no haloes or lines due to any other substance were detected for *A* or *B*. So far then our tests show that although alkali-soluble silica is present in heated chrysotile centrifuging results only in the separation of free haematite, but does not succeed in separating a low refractive index component from the forsterite. These results suggest that Professor Tilley's equation is on the right lines, but do not exclude the possibility of the formation of an intermediate amorphous magnesium silicate particularly in chrysotile heated for shorter periods at temperatures below 1000° C. The following reaction may also play a part in the thermal decomposition of the mineral:

$$H_4Mg_3Si_2O_9 \rightarrow Mg_3Si_2O_9 \text{ (amorphous)} + 2H_2O.$$

The X-ray pattern of sample no. 3 (pl. XIX, fig. 1) is so well oriented that an attempt was made to describe the orientation. From comparison with a rotation photograph of an olivine crystal about the *b*-axis [010] it was obvious that a proportion of the forsterite crystallites must be oriented in that direction and also obvious that the larger layer-line spacing of 20·8 Å. demands one or more additional orientations. The axial ratios of forsterite and olivine are sufficiently close to permit the use of the unit-cell dimensions of olivine for calculating the orientation of forsterite from the layer-lines on our photographs. The unit cell of olivine has the dimensions *a* 4·755, *b* 10·21, *c* 5·985 Å., and the layer-line spacing of 20·8 Å. corresponds closely to the axis [013]. It seems probable that the breakdown of chrysotile fibre at comparatively low temperatures would involve restricted atomic rearrangement, in particular small rotations and shifts of the silica tetrahedra. In the accepted crystal-structure of forsterite the silica tetrahedra are pointing with a tetrahedron face-diagonal along the *b*-axis [010]. If the SiO_4 groups of the chrysotile during heating build up into forsterite crystallites there are seven possible orientations of the forsterite crystallites which have their SiO_4 groups pointing with their face-diagonals along the original

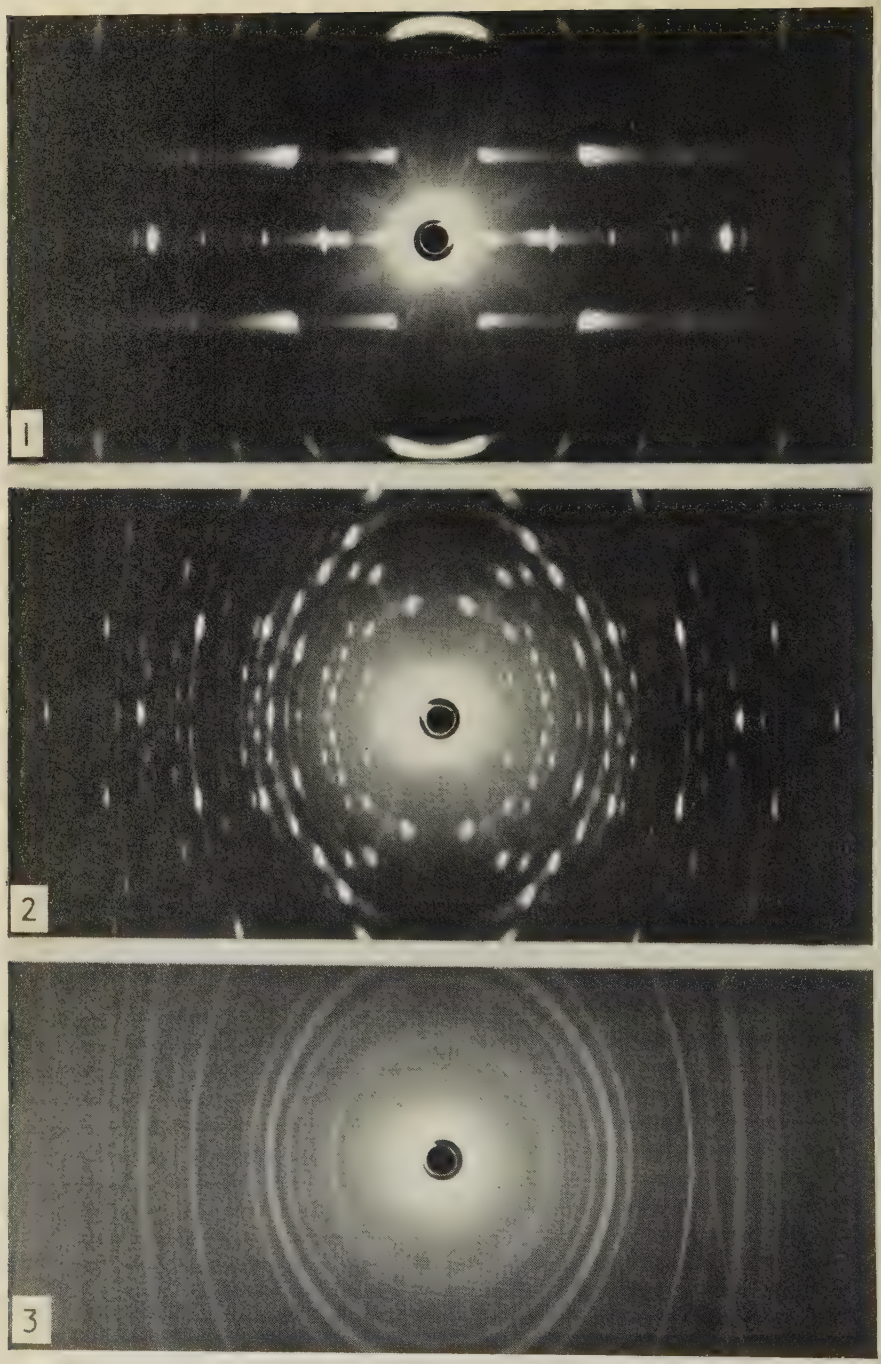
fibre axis of the chrysotile. The seven possible directions are [010], [013], [323], [653], [12.1.3], [610], [619]. Of these Aruja has already determined the first two from his photographs. The remaining axes would give layer-line spacings 19·6, 61·2, 60·7, 30·3, and 61·8 Å. We have not been able to detect spots close to the equator corresponding to a layer-line spacing larger than 20·8 Å. Thus no evidence has been found for the orientations [653], [12.1.3], [610], or [619]. The axis [323] has a layer-line spacing 19·6 Å. so close to that for [013] that any mis-setting of the fibre axis would invalidate any attempt to deduce too much detail from layer-line measurements. The shape of the elongated spots resulting from a fibre photograph also limits the accuracy of such measurements.

The changes in refractive index of heated chrysotile and the low birefringence can possibly be explained by the mixture of minute forsterite crystallites embedded in seven different directions in amorphous silica or magnesium silicate. If chrysotile decomposes into forsterite, free silica, and water then the calculated refractive index of the mixture is 1·61 and the percentage of free silica formed should be 12·5. Our figures for chrysotile heated to 900° C. for 5 hours yield a lower refractive index and a higher quantity of alkali-soluble silica. This is evidence for the intermediate reaction involving the formation of amorphous magnesium silicate. There are still too many unknown factors to account quantitatively for the observed refractive indices and the sign of elongation of the heated fibres. It should not be overlooked, however, that the phenomenon of form-birefringence successfully applied to the anomalous optical properties of, for example, chalcedony and vaterite by J. D. H. Donnay[1] may also be involved. In particular, the change from positive to negative elongation on more prolonged heating of the fibres at 1000° C. which accompanies the increase in forsterite without change in orientation may be due essentially to form-birefringence.

Since the above account was written Dr. Aruja has brought to our notice the recent work of W. Epprecht and E. Brandenberger.[2] They have made careful dehydration and X-ray studies which do not differ significantly from our results. We are, however, unable to agree with their orientation of the forsterite crystallites. It is difficult to see what X-ray evidence is available for the orientation of the *a* and *c* axes of forsterite relative to the original axes of chrysotile. Both Aruja's X-ray photographs and ours are convincing evidence of a 20·8 Å. spacing lying

[1] J. D. H. Donnay, Ann. (Bull.) Soc. Géol. Belgique, 1936, vol. 59, pp. B 215, B 289. [M.A. **6**–460.]

[2] W. Epprecht and E. Brandenberger, Schweiz. Min. Petr. Mitt., 1946, vol. 26, p. 229. [M.A. **10**–298.]



M. H. Hey and F. A. Bannister: X-ray photographs of chrysotile (unheated and heated).

along the fibre axis. Neither Epprecht and Brandenberger nor ourselves have been able to determine the exact nature of the amorphous phase or phases which may be formed during the transformation.

Explanation of Plate XIX.

X-ray photographs with filtered cobalt radiation λ 1·7889 taken in a cylindrical camera (6 cm. diameter). Actual size.

Fig. 1. Rotating sheaf of oil-green fibres of chrysotile from Johnson mine, Thetford, Quebec (B.M. 83118).

Fig. 2. Stationary compact straw-yellow fibrous aggregate obtained by heating chrysotile to 1000° C. for 12 hours (sample 3, page 334). Only spots and lines due to forsterite can be detected on this photograph. Allowing for possible mis-setting all the spots can be explained by the axes [010] and [013] of forsterite lying along the fibre axis of the original chrysotile.

Fig. 3. Rotation photograph of the fraction of specific gravity $<2{\cdot}85$ obtained by powdering heated sample 1, page 334, which yielded the highest silica extraction 18·8 %, and after powdering centrifuging in bromoform. Only the powder lines of forsterite are present on this photograph.

Dickite and collophane in the Magnesian Limestone of Durham.

(With Plate XX.)

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With a chemical analysis by C. O. Harvey, B.Sc.[1]

[Read January 22, 1948.]

IN the course of examining the cores of a boring for water at Hesleden Dene, near Castle Eden, Co. Durham (no. 2 borehole), Mr. A. Fowler noticed a cream-coloured flaky mineral of talcose aspect coating joints in the Magnesian Limestone (Permian), at depths below surface of 246 to 250 feet. The rock at these depths is an impure dolomite mudstone (Geological Survey Slice, no. E. 21304) resembling the Marl Slate, and carrying ostracods, foraminifera, and sponge spicules. Investigation of the coatings in specimens sent in by Mr. Fowler and by Mr. W. Anderson has shown that the flaky mineral is dickite, and that it is associated with fluorite, baryte, galena, zinc-blende, pyrite, and collophane. Dr. J. Phemister had previously concluded on optical evidence that dickite might be present among the minerals of metalliferous affinities discovered in the Magnesium Limestone by Mr. Fowler.[2]

The coating, scraped from the joint surfaces, was centrifuged in a bromoform–benzene mixture of specific gravity 2·75. The light crop carried the flaky mineral, with a little dolomite which was removed by treatment overnight with cold N/10 hydrochloric acid. The heavy crop was centrifuged in bromoform of specific gravity 2·89, a light fraction consisting of dolomite and a heavy fraction with colourless or faintly purple cubes of fluorite averaging about 0·1 mm., yellow zinc-blende, and euhedra of galena and baryte being obtained.

Dickite.

The dickite occurs as plates up to 0·5 mm. diameter, some of which show well-marked hexagonal outlines. These are aggregated into sheaf-

[1] By permission of the Director of H.M. Geological Survey.
[2] A. Fowler, Geol. Mag., 1943, vol. 80, p. 44. [M.A. **9**–258.]

like or radial clusters, and it was not found possible to isolate a single sheet. Interference-figures obtained were thus poor, but a high optic axial angle was indicated, and the mineral is probably optically positive. Extinction angles with the strong basal cleavage up to 16° were observed. The maximum and minimum refractive indices, measured by the immersion method, are 1·566 and 1·560, respectively.

Some 0·6 gram of pure concentrate was obtained and on this Mr. C. O. Harvey carried out a semi-micro analysis with the following results (Geological Survey, Lab. no. 1472, 1947):

		Atoms on basis 9(O,OH)	
SiO_2	45·4	1·99	Si,Al ... 2·00
Al_2O_3	39·2	2·03	Al ... 2·02
Fe calculated as Fe_2O_3	0·2	0·01	(OH) ... 3·91
MgO	0·3	0·02	
CaO	trace	—	
Na_2O	trace	—	
K_2O	0·2	0·01	
$H_2O > 105°$ C.	13·4	3·91	
$H_2O < 105°$ C.	0·4		
TiO_2	nil		
P_2O_5	nil		
MnO	nil		
CO_2	trace		
F	n.d.		
Carbonaceous matter*	1·0		
	100·1		

* Loss on ignition, other than H_2O.

This yields the formula $(Si,Al)_{2·00}(Al)_{2·02}(OH)_{3·91}O_{5·09}$, which may be compared with the ideal formula for the minerals of the kaolin group, $Si_2Al_2(OH)_4O_5$.

C. S. Ross and P. F. Kerr,[1] who established dickite as a species distinct from kaolinite, state that dickite most commonly occurs in association with metallic minerals; and recently Ross[2] has gone farther and suggested that where hydrothermal processes are clearly indicated, dickite forms rather than kaolinite. W. A. Tarr[3] and V. T. Allen[4] have accepted a hydrothermal origin for the mineral at localities far removed from proved igneous activity, while W. D. Keller[5] accepts an origin from warm

[1] C. S. Ross and P. F. Kerr, Amer. Min., 1930, vol. 15, p. 34; Prof. Paper U.S. Geol. Surv., 1931, no. 165 E, p. 158. [M.A. **4**–247, **5**–359.]

[2] C. S. Ross, Journ. Amer. Ceramic Soc., 1945, vol. 28, p. 182.

[3] W. A. Tarr, Econ. Geol., 1936, vol. 31, p. 749.

[4] V. T. Allen, Amer. Min., 1936, vol. 21, p. 457. [M.A. **6**–373.]

[5] W. D. Keller, Amer. Min., 1947, vol. 32, p. 468.

solutions while doubting a necessary connexion with a magma. Dickite has, however, been recorded in a normal clay-ironstone of Coal Measure age,[1] and its presence, while suggestive, cannot be regarded as proving a hydrothermal origin for the metallic minerals in the Durham Permian.

An X-ray examination of the mineral was carried out in the Mineral Department of the British Museum of Natural History. A few flakes of the white mineral forming a thin veneer on magnesian limestone from Durham were powdered and a rotation photograph of the preparation taken. The powder pattern obtained (pl. XX, fig. 2) is identical in spacings and relative intensities with that of powdered dickite from Red Mountain, Colorado (fig. 3). A rotation photograph (fig. 1) of a single flake shows that it is polycrystalline with preferred orientation yielding enhanced low-order basal diffractions. The dickite from Durham does not, however, yield photographs with well-defined high-order lines as do powdered samples of well-crystallized dickite from Colorado and Anglesey. Minute hexagonal flakes from both latter localities yield single-crystal photographs and when powdered high-order lines are easily visible and resolved into $\alpha_1\alpha_2$ doublets. The rather poor optic pictures and relatively weak powder lines of the dickite from Durham are probably due to the extreme thinness of the individual flakes making up the oriented aggregates. This does not, however, prevent a satisfactory identification of the mineral. All the dickite photographs are clearly distinguished from those of kaolinite from Cornwall and nacrite from Saxony (figs. 4, 5). The reproductions of the X-ray photographs of these three minerals illustrate the diagnostic value of sharply defined powder patterns obtained with minute samples in a small-diameter camera.

Collophane.

One of the specimens from which dickite was obtained was found to have in it a concretion or filled gash carrying an intergrowth of zinc-blende with a brown phosphate mineral which in thin section (E. 22285) appeared mainly isotropic but passing into small birefringent areas. Immersed in oils, some birefringent grains yielded an apparently positive biaxial interference-figure with 2V approximately 20°, and refractive indices α 1·608, γ 1·614. Brown patches resembling glue and, therefore, entirely characteristic of collophane are adjacent on the hand-specimen to a golden-brown transparent variety, specific gravity 3·00, also showing marked anisotropism.

[1] P. G. H. Boswell, Mineralogy of sedimentary rocks. London, 1933, p. 115.

X-ray photographs, with filtered copper radiation, of fragments of the glue-like and transparent collophane (pl. XX, fig. 6) were taken. Both photographs proved to be powder patterns identical with each other and closely resembling that of powdered apatite (var. asparagus-stone) from Murcia, Spain (fig. 7). A fragment of the anisotropic transparent 'collophane' was then oriented with the negative extinction direction normal to the incident X-ray beam. The fragment was not rotated during exposure so that the optimum conditions existed for the determination of a 'fibre axis' in the fragment. The powder photograph obtained revealed no preferred orientation and the powder lines are smooth and sharp. Hence typical collophane and also the transparent variety from Durham are identical and belong to the apatite family. Moreover, the average size of the crystallites must lie between 0·5 and 5 μ. It is interesting to record that during the X-ray exposures the brown transparent fragments of 'collophane' lose their transparency and become glue-like. This is possibly due to the removal of moisture locked between the minute crystallites by the heating of the fragments when exposed to X-rays. When the fragments are immersed in water or a refractive index oil they become transparent again and also birefringent.

We have not succeeded in finding any completely satisfactory explanation of the positive anisotropy of the collophane. Although J. D. H. Donnay[1] has applied with success O. Wiener's[2] theory of form-birefringence to vaterite, chalcedony, and nemalite, it is difficult by this theory to reconcile the low water-content[3] of collophane with its optical sign. Strain-birefringence may account, however, quite satisfactorily for anomalous birefringence, and the low value of refractive index of collophane, as for all fine-grained aggregates, must then be attributed to porosity.

No accurate chemical analysis of collophane from Durham has been carried out, but fragments of the Durham mineral when treated with dilute hydrochloric or nitric acids effervesce quietly and continuously until solution is complete, thus showing that this collophane is a carbonate-apatite. It is indeed probable that the composition of the Durham mineral is similar to that of collophane from other localities and is essentially fine-grained francolite.

[1] J. D. H. Donnay, Ann. (Bull.) Soc. Géol. Belgique, 1936, vol. 59, pp. B 215, B 289 [M.A. 6–460]; Univ. Toronto Studies, Geol. Ser., 1945, no. 49, p. 5 [M.A. 10–160].

[2] O. Wiener, Abh. math.-phys. Kl. sächs. Gesell. Wiss., 1912, vol. 32, p. 507.

[3] $H_2O < 105°$ C. 1·0 %, $H_2O > 105°$ C. 1·1 %, determined by C. O. Harvey.

This would agree with C. Frondel's conclusions, which were based upon collophane specimens from many localities.[1] Frondel rightly identified collophane with a member of the apatite series by means of X-ray powder photographs and concluded that most collophanes, so far studied by modern techniques, are undoubtedly finely crystalline francolites containing varying amounts of adsorbed water and, therefore, exhibiting variable specific gravities and refractive indices. In his opinion and ours, F. Sandberger's original analysis[2] corresponds to a carbonate-hydroxyl-apatite (dahllite). Sandberger wrongly deducted the CO_2 content and may have overlooked a probable fluorine content.

Explanation of Plate XX.

X-ray diffraction photographs taken in a 6 cm. diameter camera with filtered copper radiation. A length of 14·72 cm. on the original films is equivalent to 10 cm. on the reproduced figures.

Fig. 1. Flake aggregate of dickite from a core in the Magnesian Limestone, Hesledene Dene, Co. Durham, rotating about a direction in the plane of the flake. Geol. Survey, E. 21304.

Fig. 2. Powdered flake aggregates of dickite from a core in the Magnesian Limestone, Hesledene Dene, Co. Durham. Geol. Survey, E. 21304.

Fig. 3. Powdered crystals of dickite from Red Mountain, San Juan Co., Colorado. B.M. 1923, 393.

Fig. 4. Kaolinite from Cornwall; portion of a washed sample of china-clay studied by G. W. Brindley and K. Robinson, Min. Mag., 1946, vol. 27, p. 244, no. 1 of table I.

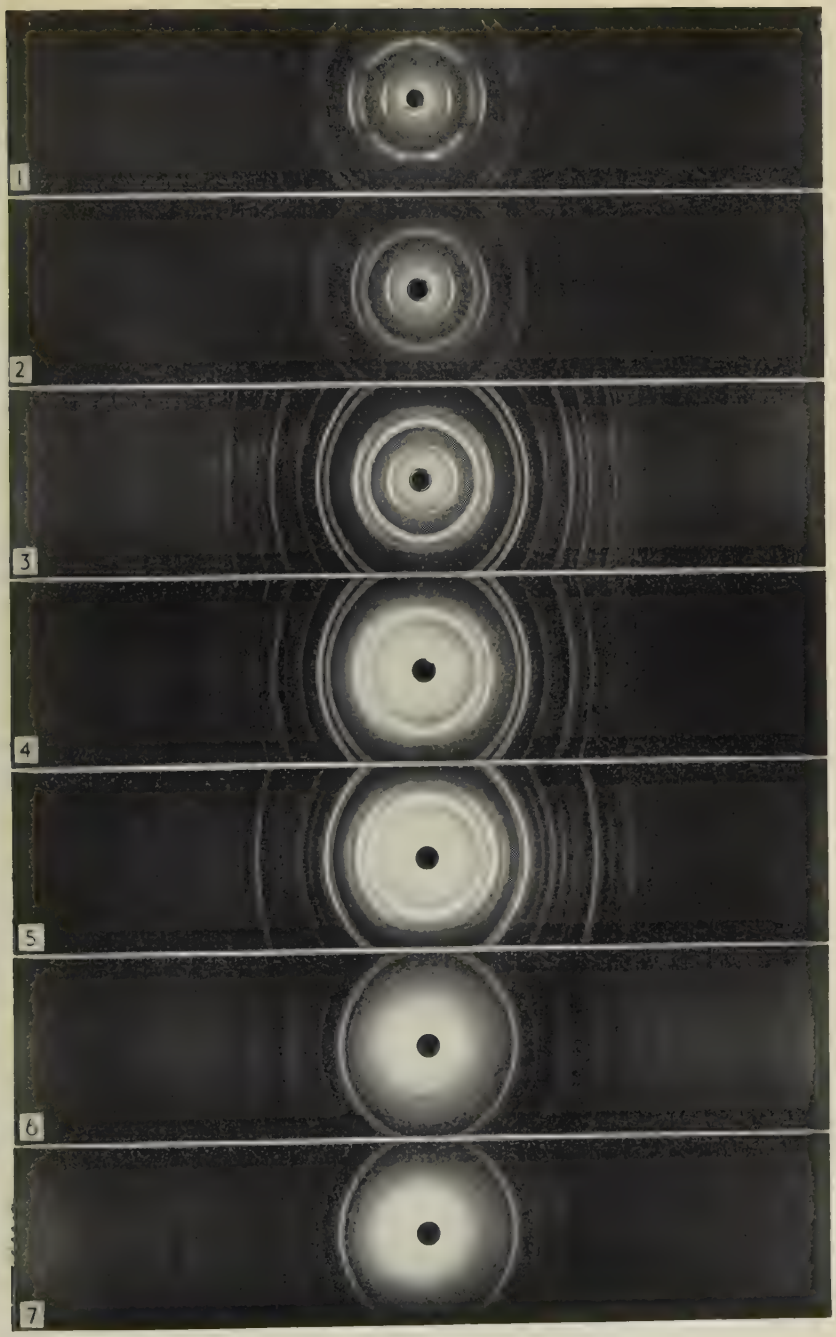
Fig. 5. Powdered stellate aggregates of nacrite from Freiberg, Saxony. B.M. 31086.

Fig. 6. Fragment of anisotropic collophane from a core in the Magnesian Limestone, Hesledene Dene, Co. Durham. Geol. Survey, E. 22285.

Fig. 7. Powdered crystals of fluor-apatite from Jumilla, Murcia, Spain. B.M. 60729.

[1] C. Frondel, Amer. Min., 1943, vol. 28, p. 215. [M.A. 9–33.]

[2] F. Sandberger, Neues Jahrb. Min., 1870, p. 308.



K. C. Dunham, G. F. Claringbull, and F. A. Bannister: X-ray photographs of dickite and collophane.

Ganophyllite from the Benallt mine, Rhiw, Carnarvonshire.

(With Plate XXI.)

By W. Campbell Smith, M.C., T.D., M.A., Sc.D.

Keeper of Minerals, British Museum.

With X-ray data by F. A. Bannister, M.A., Sc.D., F.Inst.P.

[Read June 26, 1947, and April 1, 1948.]

GANOPHYLLITE was first detected in the Benallt mine as small fibrous patches varying in colour from pale pink to brown, in the thin vein cutting ore in the Ty Canol incline from which the manganese-rich chlorite, pennantite, was described.[1] These were identified by X-ray photographs. It had previously been found at the neighbouring Nant mine by Sir Arthur Russell[2] in 1911.

During my visit with Dr. A. W. Groves to the Benallt manganese mine in June, 1945, glistening brown flakes of the mineral were found at several places, associated with calcite, on fracture surfaces in the manganese ore. The best specimen obtained at that time was found in Stope 73 by Mr. Pickering (B.M. 1945,109), and another fine specimen was collected later in the year by Mr. T. J. A. Wills, the mine manager, at Peg 31 on the 60-foot level (B.M. 1945,131).

On all the specimens obtained the ganophyllite occurs as very small six-sided flakes, cinnamon-brown in colour, and with a brilliant lustre which ranges from pearly to metallic or micaceous. None of the flakes exceeds 1 mm. in longest dimension.[3] They have a perfect mica-like cleavage. The crystals are biaxial, optically negative, with 2E varying in measured flakes from 30 to 40°, and the acute bisectrix is at right angles to the perfect cleavage. Refractive indices, on several specimens, measured by the immersion method in sodium-light, are for β between 1·610 and 1·612. Estimates of birefringence based on universal-stage

[1] W. Campbell Smith, F. A. Bannister, and M. H. Hey, Min. Mag., 1946, vol. 27, p. 218.

[2] A. Russell, Min. Mag., 1946, vol. 27, p. 234.

[3] A specimen obtained earlier and given me by Mr. Wills had flakes up to 4 mm. across, but it is not known from which part of the mine this was obtained. The ganophyllite is associated with white calcite which fluoresces pink in ultra-violet light. (B.M. 1945,108.)

measurements of retardation and the microscope method of measuring thickness gave $\gamma-\alpha$ 0·040$\pm$0·003, $\gamma-\beta$ 0·001.

The pleochroism observed in thin sections is: α', perpendicular to the cleavage, straw-yellow; β and γ' parallel to the cleavage, colourless.[1] The cleavage flakes show no perceptible pleochroism.

Qualitative chemical tests established the presence of much manganese and of water given off at a low temperature in the closed tube. No further chemical work was done as the amount of available material was small. An approximate value for the specific gravity is 2·8. The identification with ganophyllite is confirmed by X-ray photographs, the evidence from which is discussed below.

Ganophyllite was first described from the Harstig mine, Pajsberg, Sweden, by A. Hamberg in 1890.[2] On crystals, which were up to an inch in length but presented very poor faces for measurement, Hamberg found a prism angle (110):(1$\bar{1}$0) of 44° 49′. A basal cleavage flake of one of these prismatic crystals thus shows pairs of edges making plane angles of about 44° and 136°, and the symmetry plane (010) bisects the obtuse angles (136°). The perfect micaceous cleavage was taken as the base, *c* (001) (text-fig. 1*a*).

Hamberg gave as the value for the optic axial angle, $2E_{Na}$ 41° 53′, negative. He measured the refractive indices, β and γ, by means of a 30° prism of which the perfect cleavage formed one face, but the second face was so poorly polished that it was necessary to attach a cover-glass to it with Canada balsam to improve the light transmission. The values he obtained by this method, β 1·7287, γ 1·7298, were shown by Larsen and Shannon[3] to be quite incorrect and they redetermined them by the immersion method as α 1·573, β 1·603, γ 1·604. The optical orientation is given by Hamberg (loc. cit., p. 586) as: 'the plane of the optic axes is perpendicular to the symmetry plane and perpendicular to the base. . . . The acute bisectrix is perpendicular to the base.' Thus his setting of the optical orientation is therefore $\alpha = c$, $\beta = a$, $\gamma = b$ (text-fig. 1*a*′).

E. S. Larsen in 'The microscopic determination of the nonopaque minerals' (1921, p. 267, and 2nd edit., 1934, p. 167) has given a different orientation, '$X \wedge c$ = small. $Y = b$', and this has been followed by W. E. Ford in Dana's 'Textbook of mineralogy' (4th edit., 1932, p. 641),

[1] A similar absorption scheme is recorded for a mineral taken to be a mica in one of the specimens carrying banalsite from Benallt described in 1944 (Min. Mag., vol. 27, p. 40).

[2] A. Hamberg, Geol. För. Förh. Stockholm, 1890, vol. 12, pp. 586–598.

[3] E. S. Larsen and E. V. Shannon, Ganophyllite from Franklin Furnace, New Jersey. Amer. Min., 1924, vol. 9, p. 239. [M.A. **3**–216.]

who gives the characters as: 'Optically −. Ax. pl. || (010). *X* nearly || *c* axis.'

Our observations and particularly the series of X-ray photographs taken by Dr. Bannister confirm the correctness of Hamberg's statement for the Harstig ganophyllite that the optic axial plane is perpendicular to the plane of symmetry (010), but the statement by Larsen that the orientation of the optic axial plane is parallel to (010) is of particular interest as we find in specimens from different parts of the Benallt mine examples of both orientations. This discovery is due to Dr. Bannister, who found for the first of several specimens from Benallt of which he took X-ray photographs that the optic axial plane was parallel to the plane of symmetry. Other specimens agreed with the Harstig ganophyllite in having the axial plane perpendicular to the plane of symmetry, but we subsequently found a second specimen with the parallel orientation. In every case Dr. Bannister's observations are confirmed by our optical measurements on flakes of the several specimens.

Our confirmation of Hamberg's orientation for the Harstig ganophyllite is based on the following observations on a specimen in the British Museum collection (80037). As mentioned above, the cleavage flakes are bounded by edges making plane angles of about 44° and 136°, and the plane (010) in Hamberg's setting bisects the obtuse angle of 136°. The plane of the optic axis is at right angles to the trace of this (010) plane.

The existence of a plane of symmetry in this position is confirmed by a Laue photograph taken by Dr. Bannister of a flake from the Harstig ganophyllite set with the plane bisecting the 136° angle between the bounding edges vertical (pl. XXI, fig. 1), the optic axial plane being horizontal. The flake in this position rotated about the third mean line (β), which is taken by Hamberg as parallel to the a-axis, gives a layer-line spacing of 5·6 Å. Rotated about the obtuse bisectrix (γ), parallel to the b-axis, the layer-line spacing is 13·5 Å. These spacings give a ratio $b/a = 2{\cdot}41$, which agrees sufficiently well with the axial ratios obtained by Hamberg $a:b = 0{\cdot}4130:1$, from which $b/a = 2{\cdot}42$. It has not yet been possible to determine the angle β from X-ray measurements. The value of the c (001) spacing for ganophyllite from Harstig is 12·5 Å. and has been derived from reflections on the zero layer-line of rotation photographs of flakes rotated about the a and b axes.

Returning now to the Benallt specimens, we find the mica-like flakes are bounded by edges of which two opposite pairs make angles of about

132°, and for the best specimen, from the 60-foot level (B.M. 1945,131), and several others we find the plane of the optic axes at right angles to the plane bisecting this obtuse angle. Assuming the angle of 132° to correspond with 136° measured on flakes of the Harstig ganophyllite we have the same orientation as given by Hamberg, namely, Ax. pl. $\perp$(010), $\gamma = b$. This is confirmed for B.M. 1945,131 by a rotation photograph about the third mean line (β) which gives the same, a-axis, spacing as for the Harstig ganophyllite.

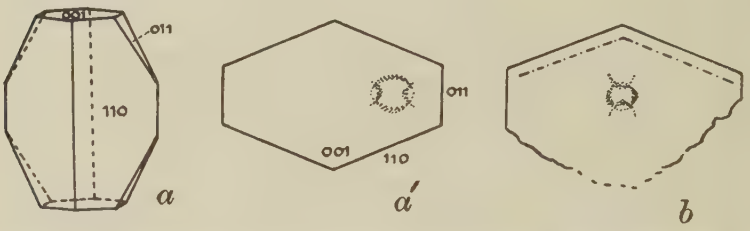


Fig. 1. (a) and (a') Tracings of Hamberg's figures of ganophyllite from the Harstig mine, Pajsberg, Sweden (loc. cit., pl. 13, figs. 8 and 9).

(b) Reduced from a tracing of a photomicrograph from the Benallt mine of the ganophyllite showing the abnormal position of the optic axial plane, parallel to (010).

A different orientation, however, was found when X-ray photographs were taken of the flakes from another specimen (B.M. 1944,36) collected by Dr. Groves in 1944 from no. 5 ore-body in the Benallt mine. The bounding edges of these flakes are poorly developed, but the position of the plane of symmetry was established by a Laue photograph and was found to be *parallel* to the optic axial plane. Moreover, a rotation photograph taken with the third mean line vertical gave a spacing of 13·5 Å., corresponding to b for the Harstig ganophyllite, while a rotation photograph with the positive obtuse bisectrix vertical gives the a-axis spacing of 5·6 Å. Thus for this specimen the orientation is $\beta = b$, $\gamma = a$, which is the orientation given by Larsen. The optic axial angles observed in flakes of this specimen vary considerably, some flakes being nearly uniaxial, but values up to 27° for 2E were measured, and the flake selected by Dr. Bannister was one with a clearly defined axial angle. His determination of the 'parallel' orientation was subsequently confirmed by examination of other flakes and of several crystals measured in a thin section cut across the specimen B.M. 1944,36 in which the ganophyllite occurs in thin veins traversing the ore. Text-fig. 1b is a tracing from a photomicrograph of one such section. Lines of inclusions, parallel

to the prism faces m and m''', are at a plane angle of about 136°. The optic axial plane lies *in* the plane bisecting this angle.

One other specimen (B.M. 1945,110, from Stope 84) was found with the 'parallel' orientation of the optic axial plane. The orientation could not be definitely verified in thin flakes many of which are composite, but it was established by a rotation photograph, taken by Dr. Bannister. The flake rotated about the third mean line (β) gives the spacing found for the Harstig mineral rotated about the Bx_o (γ), which is parallel to the b-axis. The optic axial angle in flakes from this specimen is very variable, angles of 2E from 20 to 35° being observed.

The only other notable difference in the optical properties of specimens with the two different orientations is that thin sections of the specimen B.M. 1944,36 cut across the flakes show vibrations parallel to the cleavage light ochraceous buff, whereas those perpendicular to the cleavage are nearly colourless. This gives the absorption scheme $\gamma' > \alpha$, whereas for the 'normal' ganophyllite it is $\alpha > \beta = \gamma$ (p. 344). The evidence for this pleochroism seems quite definite in thin sections, but has not been confirmed by observations on flakes of the mineral.

Within the limits of errors of the immersion method as applied to thin flakes of the mineral (which are notoriously bad subjects for this method) no considerable difference in the values of β and γ has been found between flakes from specimens with the two different orientations.

For specimens with 'normal' orientation values for β in Na-light obtained at room-temperatures between 17 and 19° C. were:

Flakes with 2E 44°, β_{Na} 1·6099. (B.M. 1945,108.)
„ „ 2E 40°±1°, β_{Na} near and greater than 1·605. (BM. 1945,109.)
„ „ 2E 30°, β_{Na} 1·6099; also another reading just less than 1·6097. (B.M. 1945,131.)

γ is only slightly greater than β (see p. 344).

Similar measurements on specimens with 'parallel' orientation gave:

Flakes with 2E 17° at 19° C. gave γ_{Na} 1·6098 and β slightly less, but another determination gave γ_{Na} 1·6109. (B.M. 1944,36.)

Flakes with 2E 35° at 17° C. β and γ near 1·6120, $\beta < 1·6123$. (B.M. 1945,110.)

A single measurement of $\gamma - \alpha$ was obtained on a thick flake and gave $\gamma - \alpha = 0·038 \pm 0·001$. (B.M. 1944,36.)

Change of optical orientation on dehydration.

Hamberg in his original work on ganophyllite had shown that the mineral readily lost water when heated and that if sufficient time were allowed most of the water was re-absorbed if the mineral was left exposed

to moist air. It was this behaviour of the water in ganophyllite which led Hamberg to describe it as a mangan-zeolite.

Knowing of this property of the mineral it seemed probable that the variation in 2V and perhaps also the presence of two types of ganophyllite with differing optical orientation would be found to be related

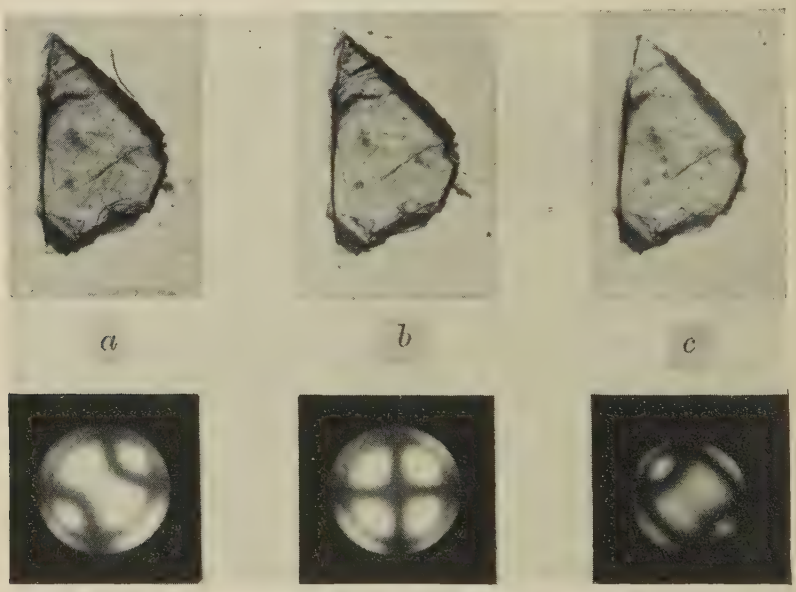


Fig. 2. Ganophyllite from Benallt mine. Change of optical orientation on heating. (*a*) Unheated. (*b*) Heated to about 50° C. for one hour. (*c*) Heated to about 105° C. for half an hour. The upper pictures show the flake seen in parallel light, and below are the corresponding optic pictures in polarized convergent light. The magnification of the flake is × 46. Length of longest edge 0·6 mm.

to the water content of the mineral in the same way as the optic axial angles and orientation of some zeolites alters when water is driven off by heating as shown by the work of F. Rinne and others.

Experiments to test this idea made on a purely qualitative scale confirmed that the optic axial angle and the optical orientation change when flakes of ganophyllite are heated and change back to the original value and position as the flakes are cooled in moist air; moreover, flakes from specimens of the two different orientations behave differently.

A flake of the ganophyllite with 'normal' orientation (B.M. 1945,131) heated in the open at about 50° C. for an hour became uniaxial. Heated

further in an air oven between 95 and 105° C. for 45 minutes the optic eyes had opened out to 35° (2E) in the plane of symmetry, at right angles to their original position. The effect is shown in text-fig. 2.

On repeating the experiment with a flake with 'parallel' orientation (B.M. 1945,36) the optic axial angle increases in the plane of symmetry to about 30° (2E).

Flakes of the two types after heating have the same optical orientation and approximately the same value of 2E.

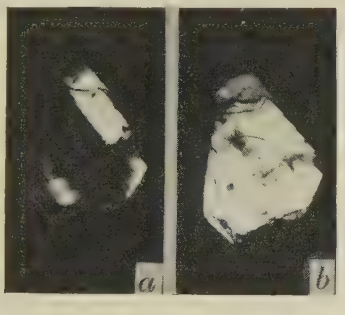


Fig. 3. The same flake (as in fig. 2) photographed in parallel polarized light at two stages during cooling. (*a*) The flake is seen when over most of its surface it is uniaxial and appears dark between crossed nicols, but in some lamellae it is still birefringent. (*b*) The same flake photographed after standing in moist air overnight: birefringence is uniform over the whole plate.

Tests at higher temperatures were made on ganophyllite from the Harstig mine. In an air oven heated to 320° C. a flake near the centre of the oven became quite opaque after an hour's heating (probably less), while a flake nearer the oven door heated probably to round about 250° C. showed the phenomenon described above, the optic eyes having opened out in the plane of symmetry to 2E 44°.

That these changes are due to loss of water is confirmed by placing flakes in a desiccator charged with concentrated H_2SO_4 under which conditions flakes of 'normal' ganophyllite become practically uniaxial within 24 hours, but the opening out in the plane at right angles was not clearly observed until the fifth day of the test.

The heated flakes on cooling in moist air slowly regain their original optical properties, just as they regain their water as Hamberg showed. It was, however, several times observed that in some parts of the flakes the recovery of the original orientation was delayed and lagged behind the other parts of the flakes. An example may be given of a flake from

B.M. 1945,131 heated for 30 minutes to 105° C. and allowed to cool. In the main part of the flake 2E fell from 44° to about 25° in 85 minutes' cooling. On further cooling for half an hour it was noticed that in one or two lamellae, bounded by edges parallel to the trace of (010), the optic eyes had ceased to close in while the rest of the flake was by now nearly uniaxial. The effect between crossed nicols in parallel light is illustrated in text-fig. 3. During the next two hours the optic eyes over the main part of the plate had opened out to 2E 20° in the plane perpendicular to the plane of symmetry, but in the lamellae the optic axial plane was still parallel to the plane of symmetry and 2E 12°. After standing overnight the whole flake had resumed its original condition. Similar lag in recovery was observed in several flakes both from Benallt and Harstig. Where the lag is in progress the effect between crossed nicols in parallel light is as of twin lamellae with edges parallel to (010).

It has not been possible with the apparatus at present available to determine the refractive indices of the flakes at various stages during these heating experiments. Attempts to determine the refractive index of flakes dried in a desiccator over concentrated H_2SO_4 show that for ganophyllite with normal orientation (B.M. 1945,131) β and γ for sodium-light are near 1·6085 (comparing with β 1·6099 for untreated material). β and γ both decrease as water is lost, γ decreasing more rapidly than β. A decrease of γ also is indicated by measurements on flakes from B.M. 1945,131 dried in a desiccator for 72 hours during which time 2E had increased from 17 to 24°.

If these determinations can be relied upon sufficiently they indicate that something other than, or more than, a difference of water content is responsible for the different optical orientation of the two types found at the Benallt mine.

In concluding this paper I must add that I am greatly indebted and very grateful to Dr. F. A. Bannister for his help, and also to Mr. D. L. Williams, assistant experimental officer in the Department, who has assisted in the heating experiments and taken the photographs.

Note on ganophyllite from Franklin Furnace, New Jersey.

It seems likely that ganophyllite from Franklin Furnace, New Jersey, where it was first recorded by Palache in 1910,[1] shows two different optical orientations. Our observations, both optical and X-ray, on a cleavage flaked from a thin blade-like crystal (similar in habit to those

[1] C. Palache, Amer. Journ. Sci., 1910, ser. 4, vol. 29, p. 187.

described by Larsen and Shannon) on a specimen of rhodonite from Franklin Furnace in the British Museum collection shows that the optical orientation is the same as for ganophyllite from Harstig, namely, axial plane perpendicular to the perfect cleavage and perpendicular to the plane of symmetry. The acute bisectrix (α) is perpendicular to the perfect cleavage which is parallel to the flat face of the blade; β is parallel to the direction of elongation. A Laue and a rotation photograph (about β) of the same flake (taken by Dr. Bannister) show unmistakably that the plane of symmetry is perpendicular to the optic axial plane, and that the cleavage face, parallel to the face of the blade-like crystals, is c (001). Thus we find, as for Harstig ganophyllite, $\alpha = c$, $\beta = a$, $\gamma = b$.

The blade-like crystals from Franklin Furnace described first as a probably new hydrated manganese silicate by Larsen and Shannon (1922)[1] and subsequently identified (1924)[2] as ganophyllite differ from the crystal examined by us. They record a micaceous cleavage, taken to be (001) and a second, perfect cleavage parallel to (100). Y (i.e. β) is nearly parallel to the length of the blades, X (i.e. α) is nearly perpendicular to the thin edge of the blade, and Z (i.e. γ) nearly perpendicular to the flat face. Moreover, sections perpendicular to Z (i.e. γ), and therefore parallel to the flat face, show twinning with composition-plane perpendicular to the face and parallel to the length and give symmetrical extinction of about 2°. Since elsewhere Larsen has given the orientation as '$X \wedge c$ = small. $Y = b$', it appears that if this orientation applies to Larsen and Shannon's ganophyllite from Franklin Furnace the flat face of the blades is (100), and the thin edge (001).

[1] E. S. Larsen and E. V. Shannon, Amer. Min., 1922, vol. 7, p. 152. [M.A. 2–472.]
[2] Ibid., 1924, vol. 9, pp. 238–240. [M.A. 3–216.]

Explanation of Plate XXI.

Fig. 1. Laue photograph of a flake of ganophyllite (B.M. 80037) from the Harstig mine, Pajsberg, Sweden, set with the plane bisecting the prism angle ($m:m''' = 44°$) vertical. The optic axial plane is horizontal. A vertical plane of symmetry is clearly seen. Crystal-film distance 3 cm. Tungsten target. (Same size.)

Fig. 2. Thin section from a specimen from no. 5 ore-body, Benallt mine (B.M. 1944,36) showing a crystal of ganophyllite bounded by edges of two prism faces making a plane angle of about 136°. The optic axial plane in this section as figured here is vertical. (×95.)

The cost of the three plates (XIX–XXI) in this issue of the Magazine (no. 201) is met by the Miers Memorial Fund.

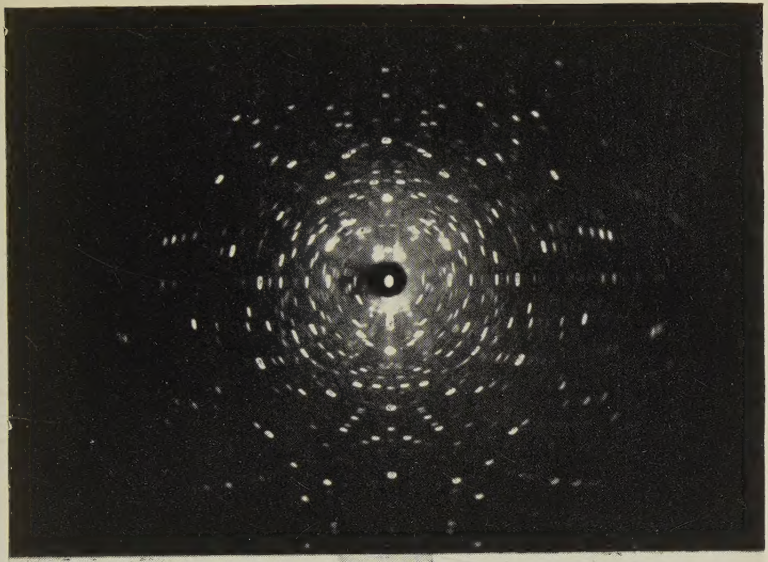


Fig. 1

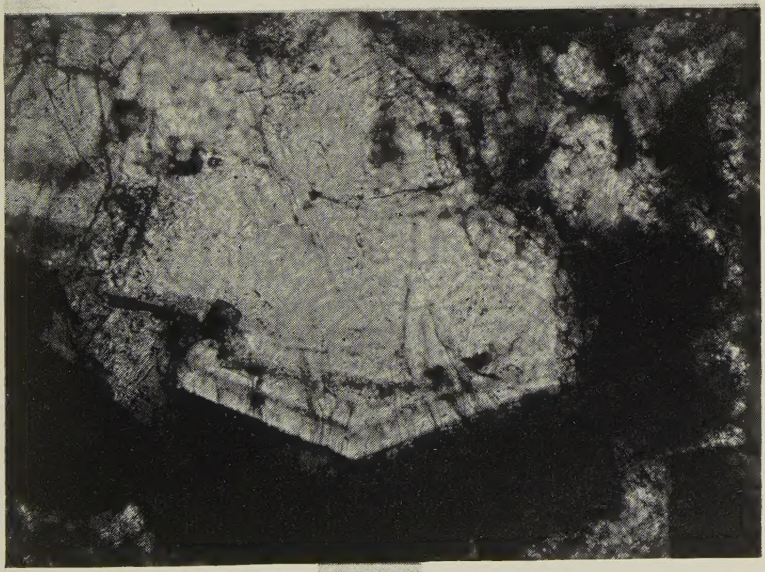


Fig. 2

W. CAMPBELL SMITH: GANOPHYLLITE.